

AN INTEGRATED MULTI-PROCESS EVALUATION OF LAND DEGRADATION IN EUROPE

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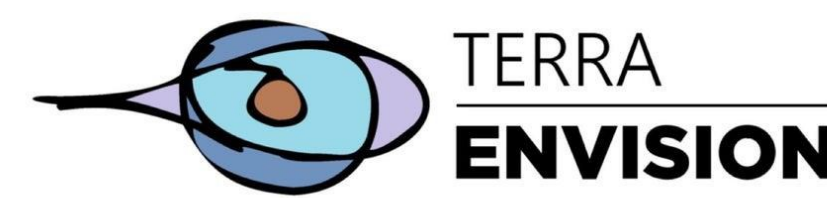
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1. CONTEXT AND OBJECTIVE:

◇ **Context:** Europe is threatened by many land degradation (LD) pathways, which have usually been explored separately in many studies focused on specific LD processes, such as water erosion (Pangos et al., 2015a,b), wind erosion (Borrelli et al., 2016, 2017a), soil compaction (Lamandé et al., 2018), soil acidification (Zamanian et al., 2024), soil salinization (Daliakopoulos et al., 2016), soil organic carbon loss (Lugato et al., 2016; De Rosa et al., 2024) or desertification (Prăvălie et al., 2017); however, an integrated and multi-scale (continental to sub-regional) assessment of the various LD processes that act across continental agricultural environments is still missing in Europe; a multi-scale evaluation of multiple LD factors can provide a solid integrative support for European policies designed to control LD processes and create pathways towards a sustainable society within the planetary boundaries;

◇ **Objective:** the spatial evaluation of multiple LD processes that are operating across continental agricultural environments, at various territorial levels (continental, national, regional and sub-regional) of Europe.

2. DATA AND METHODS:

2.1 Study area:

- this research includes 38 European countries, of which 27 are European Union (EU) member states;
- the 38 countries stretch over a total area of 5 million km², holding a cumulative agricultural area of ~2.1 million km² over the continent (CLC, 2018).

2.2 Data acquisition:

○ National and territorial boundaries:

- the integrated multi-process evaluation – performed at 5 spatial scales, namely at continental, national and NUTS (Nomenclature of Territorial Units for Statistics) 1, 2 and 3 levels of the 38 countries;
- the vector (shapefile) data for NUTS 0 (38 units, corresponding to national boundaries), NUTS 1 (major socio-economic regions, 114 units), NUTS 2 (basic regions for the application of regional policies, 307 units) and NUTS 3 (small regions for specific diagnoses, 1440 units) boundaries – acquired from the Eurostat platform (Eurostat, 2024).

○ Agricultural boundaries:

- the geospatial evaluation of LD processes – performed within agricultural areas of NUTS units, sourced from the CLC database (CLC, 2018);
- all investigations were focused on the agricultural landscapes of Europe – arable lands (2.1.1, 2.1.2, and 2.1.3 classes in the CLC nomenclature), permanent crops (2.2.1, 2.2.2, 2.2.3), pastures (2.3.1) and heterogeneous agricultural areas (2.4.1, 2.4.2, 2.4.3, 2.4.4) (CLC, 2018).

○ Land degradation data:

- the integrated multi-process evaluation – conducted based on 12 geospatial process databases available on the ESDAC platform (ESDAC, 2024): water erosion, wind erosion, soil organic carbon loss, soil salinization, soil acidification, soil compaction, soil nutrient imbalances, soil pollution via pesticides, soil pollution via heavy metals, vegetation degradation, groundwater decline and aridity;
- the 12 databases highlight the most important pathways for agricultural LD and were modelled in a previous European study (Prăvălie et al., 2024);
- all (GeoTIFF) databases used for this pan-European multi-scale inventory – freely available on the European Soil Data Centre (ESDAC, 2024).

2.3 Data processing:

○ Defining the critical LD intensity:

- the 12 LD raster data – used for this pan-European evaluation in the form of 2 classes (“Non-critical” and “Critical”);
- this binary classification – useful for identifying healthy (non-critical) and unhealthy (critical) conditions that are specific to each LD factor.

○ Mapping and quantitative evaluation of critical agricultural degradation:

- the LD geospatial layers – processed at 500 m, using the ETRS89 Lambert Azimuthal Equal Area coordinate reference system (Annoni et al., 2003);
- the 500 m data layers – the geospatial support for mapping and subsequent quantification of the absolute (in km²) and percentage (%) areas of critical LD classes across European agricultural lands, at the 5 spatial scales (the continental and the NUTS 0, 1, 2 and 3 levels);
- various software applied for the multi-process evaluation in Europe – ArcGIS (ESRI, 2020), R-package (Evans, 2020) or Inkscape (Bah, 2011).

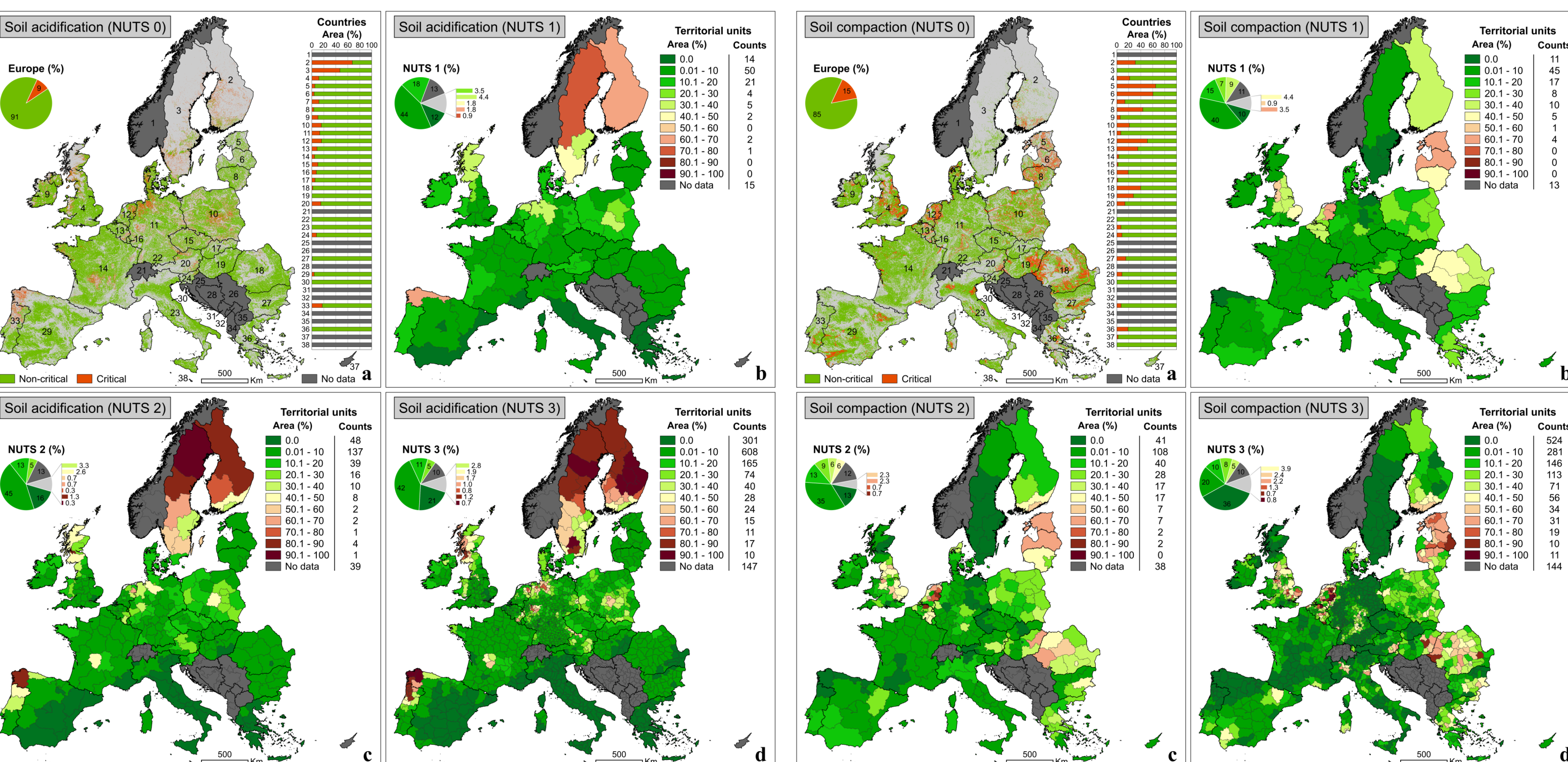


Fig. 5. Spatial pattern of soil acidification in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

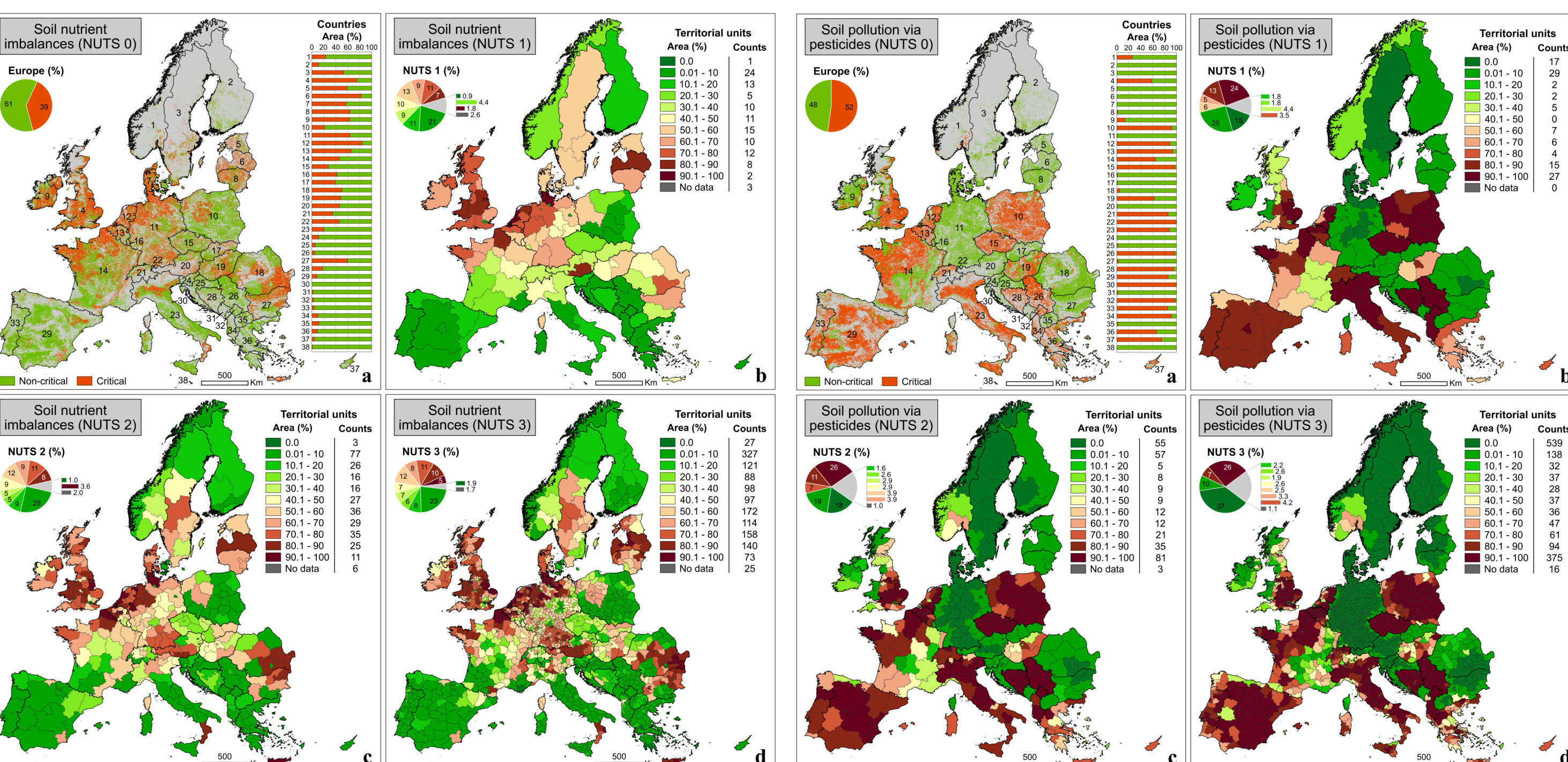


Fig. 6. Spatial pattern of soil compaction in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

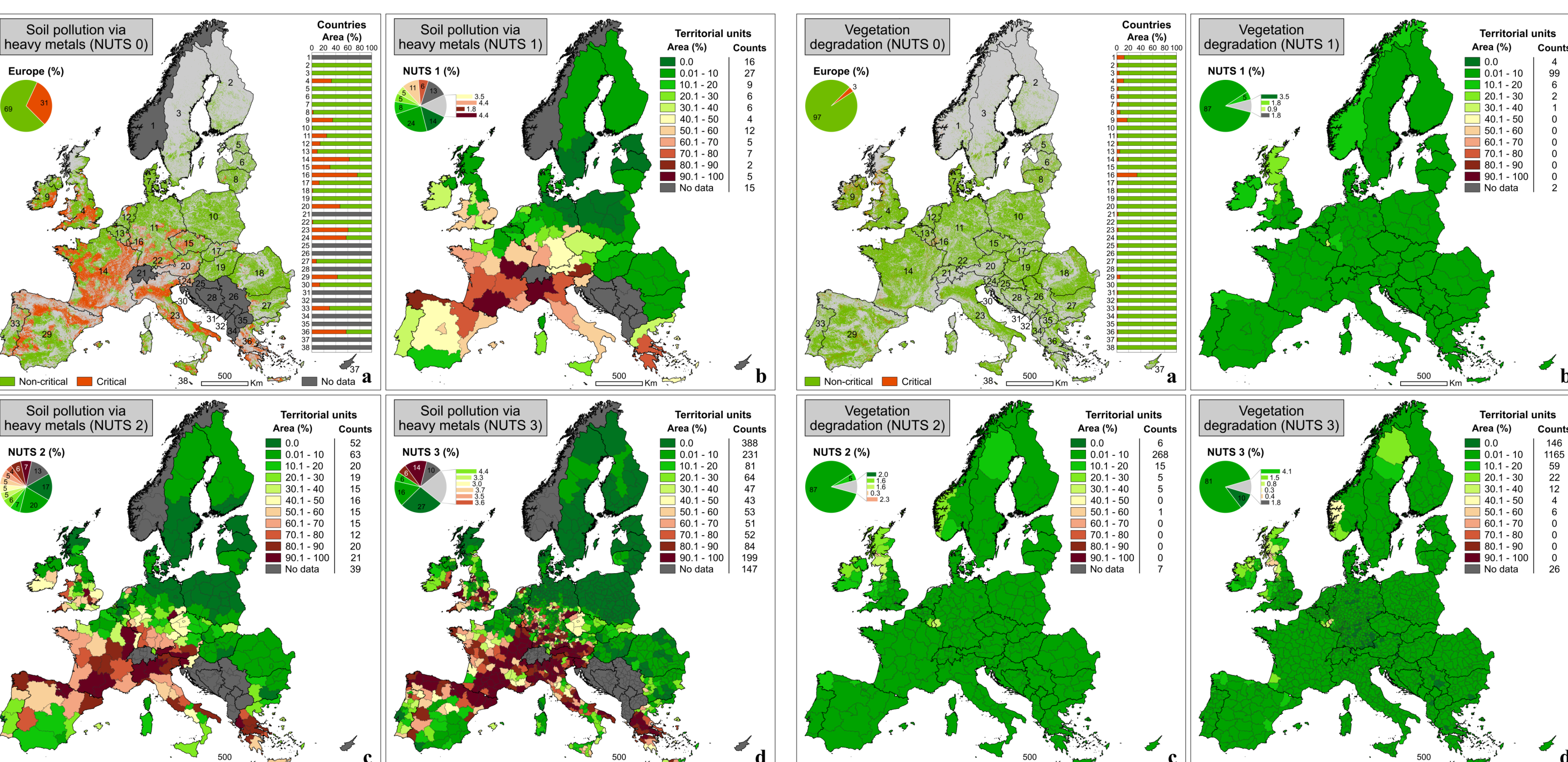


Fig. 7. Spatial pattern of soil nutrient imbalances in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.



Fig. 8. Spatial pattern of soil pollution via pesticides in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

Fig. 9. Spatial pattern of soil pollution via heavy metals in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

Fig. 10. Spatial pattern of vegetation degradation in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

Fig. 11. Spatial pattern of groundwater decline in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

Fig. 12. Spatial pattern of aridity in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

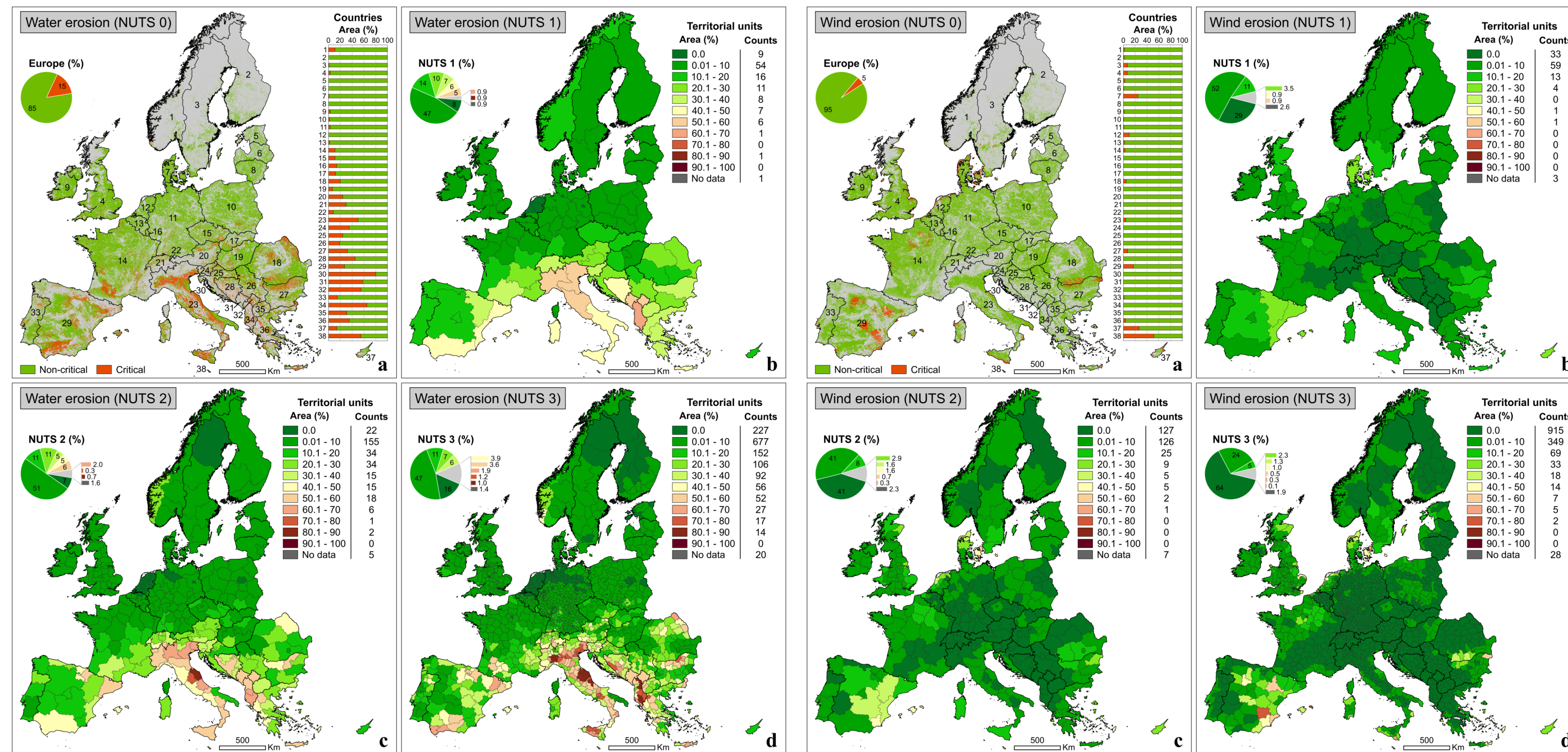


Fig. 1. Spatial pattern of soil water erosion in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

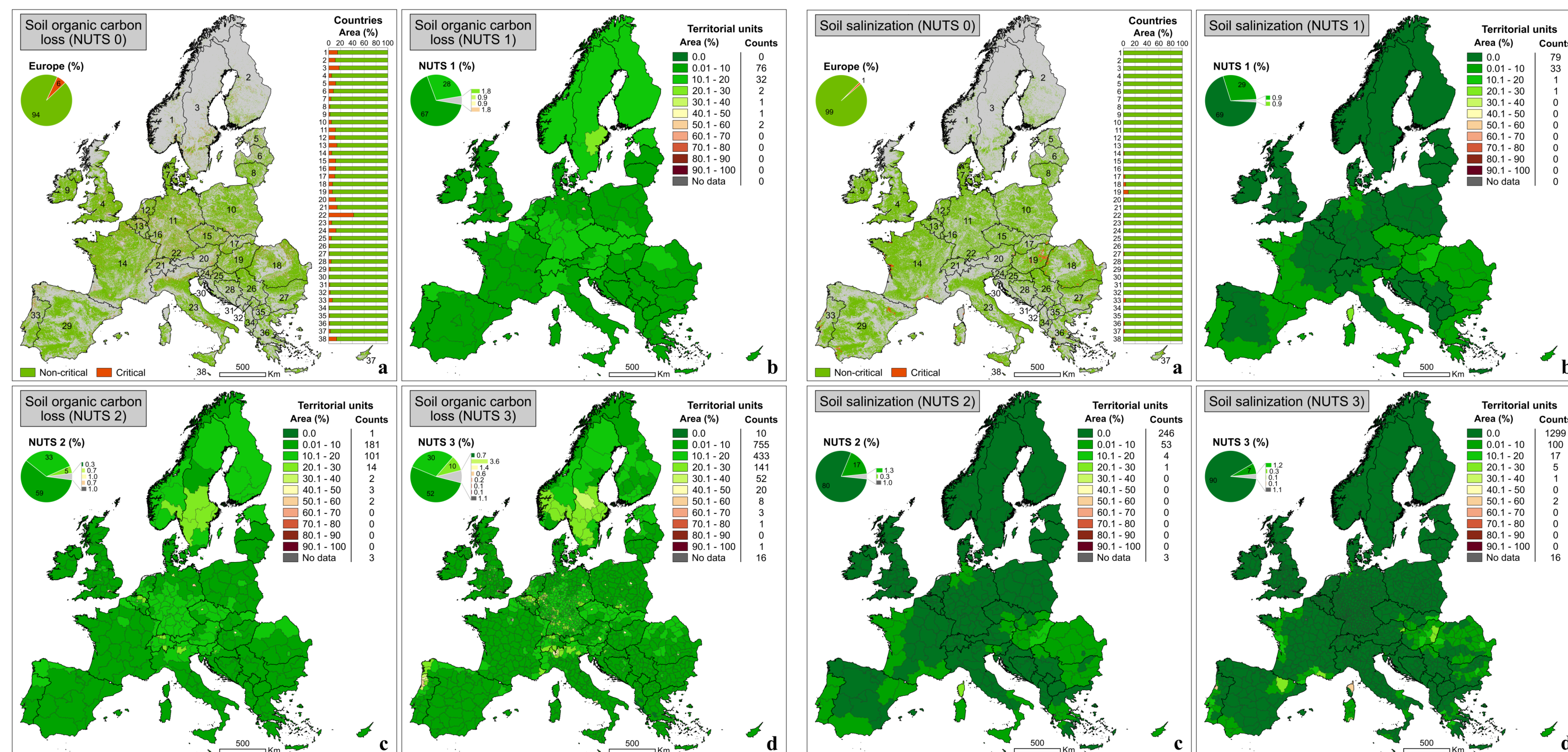


Fig. 2. Spatial pattern of soil wind erosion in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

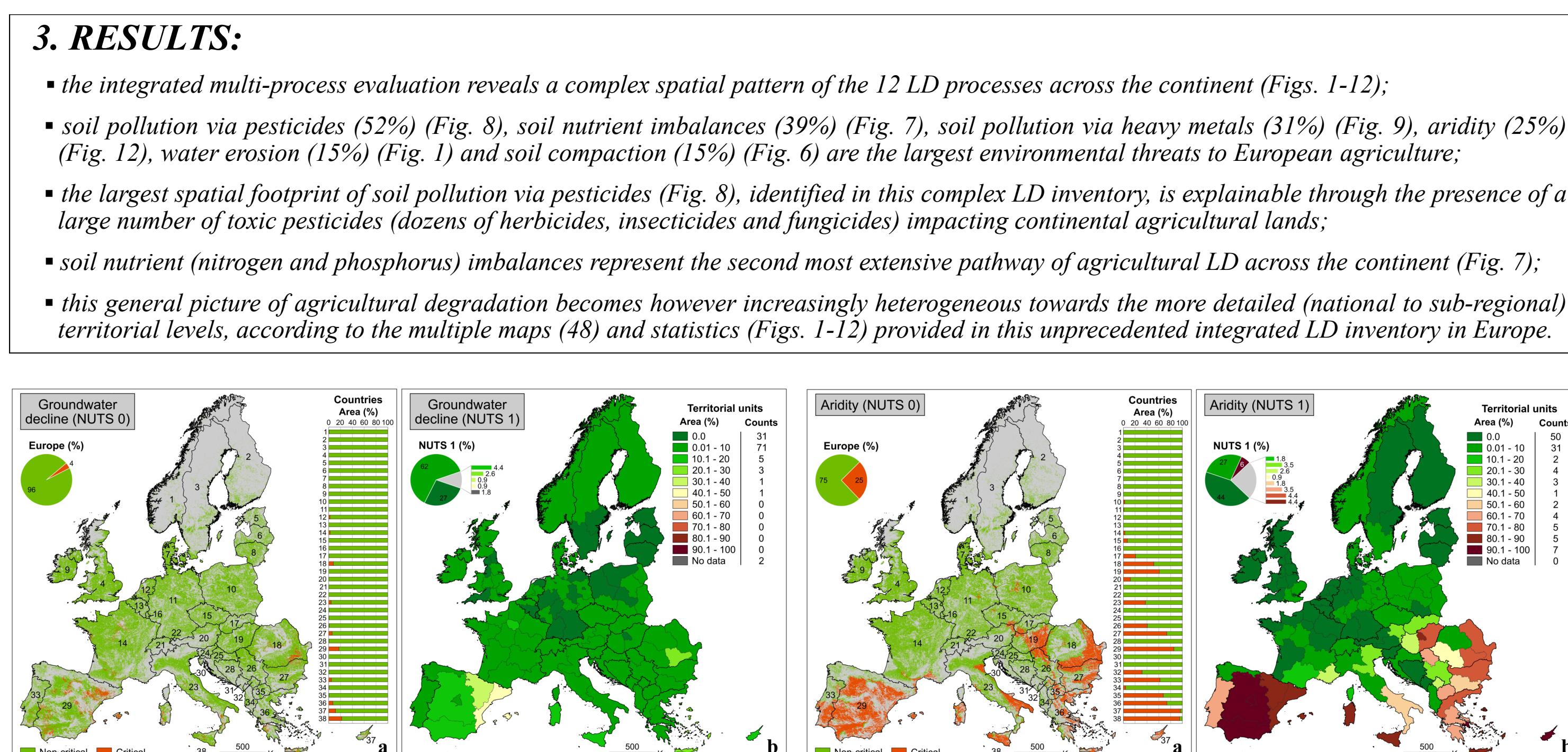


Fig. 3. Spatial pattern of soil organic carbon loss in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

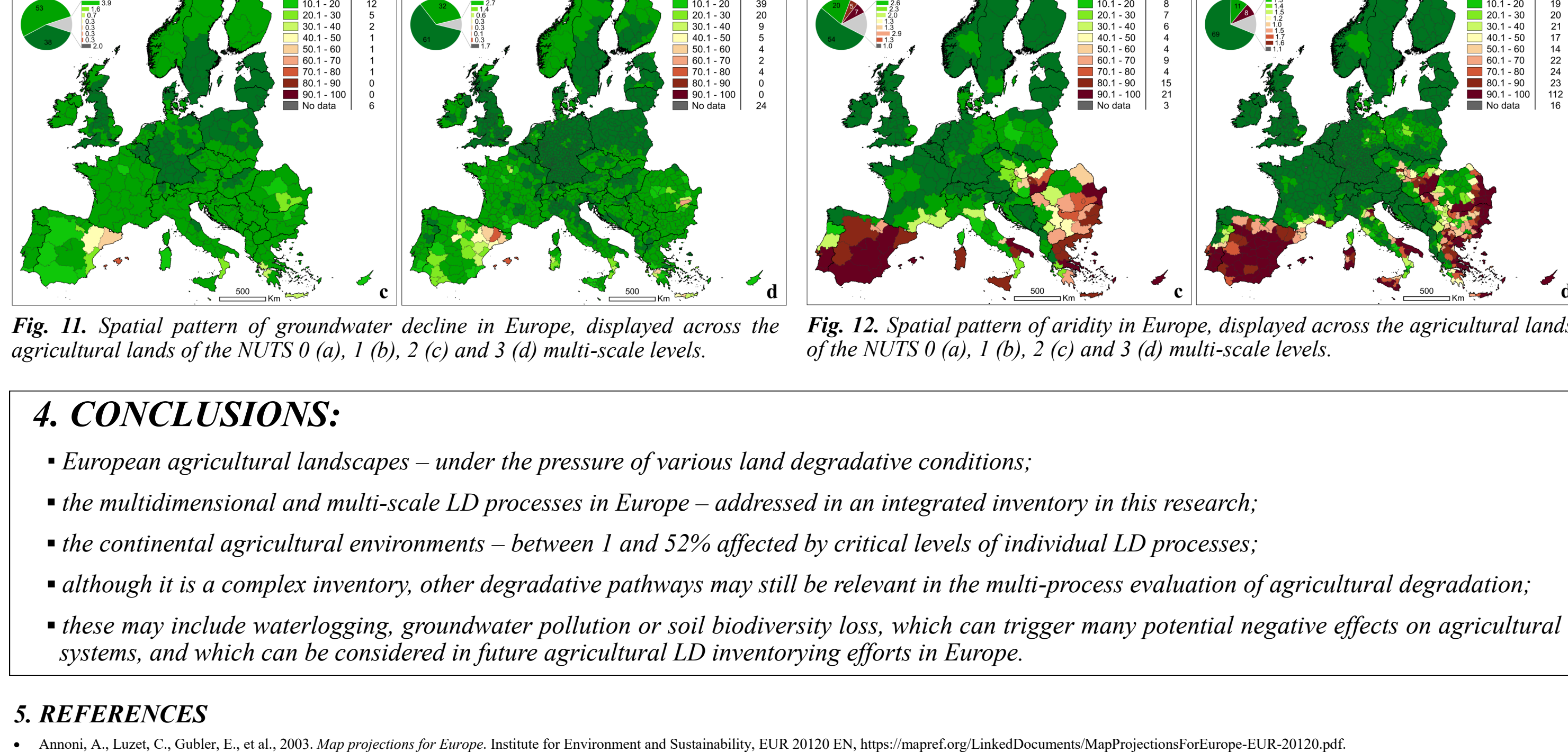


Fig. 4. Spatial pattern of soil salinization in Europe, displayed across the agricultural lands of the NUTS 0 (a), 1 (b), 2 (c) and 3 (d) multi-scale levels.

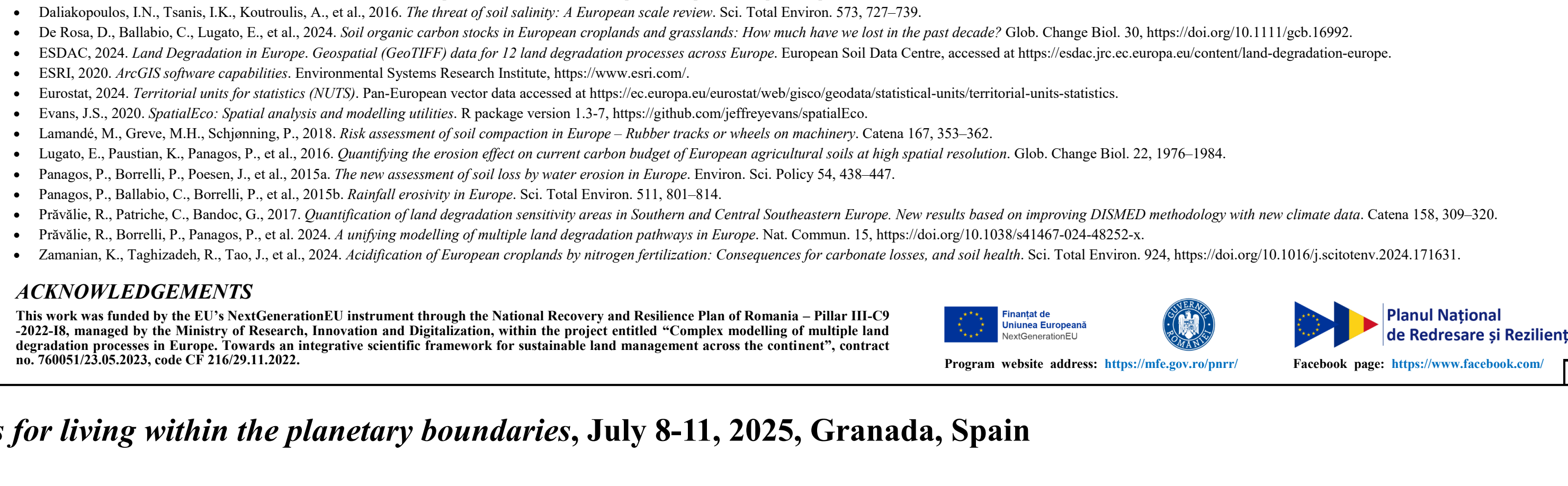


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